FAST POWER CONTROL FOR THIRD GENERATION DS-CDMA MOBILE RADIO SYSTEMS

Philippe Kauffmann
LIMOS, IUT département Informatique, BP 86, F-63172 Aubière Cedex, France

Abstract

DS-CDMA spread spectrum protocol has a better spectral efficiency than TDMA or FDMA, which makes this modulation scheme the best candidate for third generation mobile communication systems. Nevertheless, this spectral efficiency is only achieved at the cost of an advanced power control of the mobile stations. The DS-CDMA protocol uses in all mobile telephone systems a closed loop power control scheme controlled by the base station receiver. This control system is, unfortunately, not fully efficient in certain critical cases. This paper presents a much faster method than the traditional power control scheme for a given data command rate, while keeping the traditional scheme of power control bit transmission used with the IS-95, CDMA2000 and W-CDMA standards. This method makes it possible to improve the Qos (quality of service) in the difficult cases without cost.

1. Power strength change

1.1 Direct sequence spread spectrum constraints

In a DS-CDMA scheme, channel separation is obtained after the detection of the radio signal by mixing the received signal with the specific separation code of each channel in a correlator. So, for this method to be effective, the global level of the added concurrent signals has to remain under a critical level.

In the case of many transmitters linked to a single receiver (typical case of mobile stations connected to a base station) it is desirable, if the receiver capacity is to be at its maximum, that all the signals be received with the same strength [1] [2]. Strength dispersion must stay, if possible, inside a +/- 0.5 dB range.

To obtain this result, the transmission power of each competing transmitter has to be tuned from the distance by the multi-channel receiver.

Fine tuning is difficult in the mobile telephony context, because channel fading varies continuously [3]. Rake receivers which typically decode two to three signals from the same transmitter and antenna diversity help to reduce fading speed and depth, but can't prevent them completely.

1.2 Power change assessment

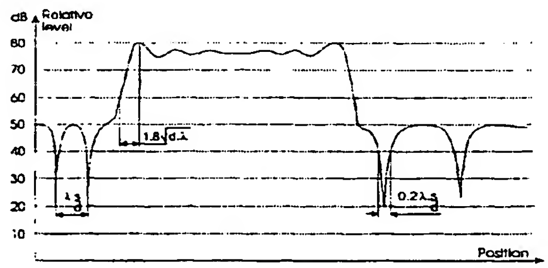

Figure 1 : Typical microwave fading channel with direct line of sight

Figure 1 shows a typical reception curve. In the middle of the figure, the receiver is in the direct signal path of the transmitter, while it receives only 30 dB lower indirect signals on the sides of the graph (typical attenuation between 20 dB and 40 dB). The limit between the two areas is called Fresnel zone [4]. The signal level change in this zone is commensurate with the size F_1 of the first Fresnel ring defined by equation (1) :

$$F_1 = \sqrt{\frac{\lambda.l.d}{l+d}}, \qquad (1)$$

λ being the wavelength of the signal, l the distance between the transmitter and the obstacle, and d the distance between the obstacle and the receiver. If l is much larger than d, the equation can be simplified and a 20 dB loss is obtained for the distance $Ad_{20} = 1.8\ F_1$, given by equation (2) deduced from (1) :

$$Ad_{20} = 1.8\sqrt{\lambda.d}\ . \qquad (2)$$

In the case of the IS95 transmission standard (900 MHz band), if the obstacle is placed 2 meters away, Ad_{20} will be 1.45 m. If the mobile and the obstacle are two vehicles crossing each other at a speed of 110 km/h, the 20 dB loss will be obtained in 24 ms, that is to say a 0.83 dB/ms drop rate, the correction capability with IS95 standard. In the case of the future W-CDMA, the situation will be the same, because if corrections are made twice as frequently, variations will be twice as fast because λ is twice smaller (1.9 GHz band). With the CDMA2000 standard the situation will even be worth.

0-7803-5977-1/00/$10.00 © 2000 IEEE

When the receiver is out of sight of the transmitter, rays having followed two or more different ways will be vectorially superimposed on the receiver's antenna, possibly causing deep attenuation lines (Rayleigh fading channel). The resulting loss can be analyzed in the deliberately simplified case of two sources with equal output power, spaced by a distance s (Young's slits experiment). Formula (3) (cf. [5]) gives in this case the strength I of the signal, y being the position of the receiver on a line parallel to the line binding the two sources, and placed at a distance d from these two sources.

$$I = 4.I_0.\cos^2\left(\frac{y.s.\pi}{d.\lambda}\right). \qquad (3)$$

It is possible to deduce from this equation the distance R_d between two lines : $R_d = \frac{\lambda.d}{s}$. The signal is attenuated by 10 dB at a 0.1 R_d distance from the trough of a line. As a result, a signal loss of more than 10 dB is obtained inside a zone of length 0.2 R_d.

Still in the case of IS95 standard : if the obstacle is at a distance d of 20 m, if the distance s between the two sources is 2 m, and if the maximum loss of the line is 30 dB, a 20 dB drop will be obtained in a distance of 0.1 R_d that is to say 33 cm. If the obstacle is a wall and the mobile a motor vehicle moving at 50 km/h, the 20 dB loss will be obtained in 24 ms too. So, as in the previous case, the drop rate will be 0.83 dB/ms.

1.3 Power control needs

The main goal of the power control algorithm is to maintain the received signal level within the best +/- 0.5 dB range, but it has a second role : to keep the receiving level inside the limits where the receiver is not disrupted (receiver dazzling or signal vanishing).

This constraint which differs from simple power control, can be qualified by the time taken to go from one power level to another with a 5 dB precision ; the power jump being any value between 5 dB and 55 dB. This can be justified by the fact that if the receiving level remains in this +/- 5 dB range reception will still remain possible.

Beyond this limit, reception errors will increase quickly. To counter this new problem, IS95, CDMA2000 and W-CDMA standards use FEC (forward error correction) with convolutional channel coding and 20 ms data frames interleaving. As long as the error rate remains under 10 % for a whole interleaving frame there is a very high probability of correction ; beyond this limit the probability decreases fast.

So, if we suppose that 20 ms interleaving frames are used (standard case for sound transmission), it can be considered that the power control system works fine if the reception level comes out of the +/- 5 dB range for less than 2 ms per frame. We will investigate in which conditions the proposed algorithm meets this requirement.

1.4 Power control mode

Open loop automatic gain control at the receiver level (with typical time response of 30 ms) is on one hand too slow to handle these very fast level changes, and on the other hand acts only simultaneously on all the signals received together, as control action is carried out before the software channel separation.

So, only fast closed loop power control is able to solve the problem satisfactorily ; it is able to treat the slower and more common channel fading problem as well.

To achieve this power control of the mobile stations, the base station periodically sends power variation orders which the mobile stations obey.

In the case of the second generation IS-95 standard, this control is obtained by inserting individual control bits inside the 20 ms data packets at a 800 Hz rate (16 times in each packet) [6]. It is accepted that the third generation system W-CDMA, will use a 1600 Hz command bit rate instead to compensate for the frequency rise, but it is admitted too that the bit rate will remain unchanged for CDMA2000 [7].

1.5 Classical method limits

Two examples of power rate change have been given in paragraph 1.2. Both show a power rate change of 0.8 dB/s, the limit for which the IS95 algorithm has been conceived. W-CDMA has the same limit, and CDMA2000 has a twice lower limit.

Now, it is quite possible to encounter variation rates two or three times higher than these given in the examples, especially in the case of fading lines. Those cases are relatively rare, but frequent enough to be harmful for the Qos of the system.

2. Distinct control algorithms

2.1 Classical control algorithm

As has already been made clear, in the traditional power control method, command bits are inserted one by one and evenly spaced in the data frames.

If a control bit is at level "1", the mobile station has to increase its transmitting power by 1 dB, in the opposite case it has to diminish its transmitting power by the same value.

2.2 Fast converging algorithm

In order to meet higher requirements, an algorithm which will be called fast converging algorithm (FCA) has been developed. This algorithm has been designed so that its reaction time is as independent as possible from the power jump needed. This point distinguishes fundamentally FCA from other algorithms.

FCA still uses bits evenly distributed in time, but the bits are considered and dealt with three by three. The action to be taken is defined in table 1.

Δ P in dB	bit 1	bit 2	bit 3
- 1	0	0	0
- 4	0	0	1
- 10	0	1	0
- 40	0	1	1
+ 1	1	1	1
+ 4	1	1	0
+ 10	1	0	1
+ 40	1	0	0

Table 1 : Power control orders

The first bit received (bit 1) points out if power has to be increased or reduced. A 1 dB increase or decrease action in power can be taken, a priori, as soon as this bit is received. The second bit (bit 2) will make it possible to distinguish between a high (10 or 40 dB) change requested and a low one (1 or 4 dB). If bit 1 and 2 constitute the sequence 0-1 or 1-0, a 10 dB change in the direction given by bit 1 will be initiated a priori. The last bit (bit 3) is used to distinguish between 1 and 10 or 4 and 40 commands. If the bit sequence of bit 1, 2 and 3 is : 0-0-1 or 0-1-1 or 1-1-0 or finally 1-0-0, the final 4 or 40 dB in the direction defined by bit 1 will be taken, otherwise nothing will be done because the right action has already been undertaken.

With this algorithm, whatever the power change needed between 5 dB and 55 dB, two 3 bit successive commands will make it possible to come back inside the working range of the receiver (power error value less then 5 dB). As an example : let us suppose that the received power drops suddenly by 32 dB, in this case a +40 dB command followed by a -10 dB command will do the trick.

Two successive commands will not be sufficient if the power change needed is over 55 dB, but this case is purely theoretical and will never arise if the power control bit rate is sufficient.

In the same way, four commands (12 bit) mean that in all cases, the best power rate (with a residual error of less then 0.5 dB) can be restored.

2.3 Bit group synchronisation

The constraint of the method is the need to synchronise reception on the three bit pattern. It will indeed always be necessary to be able to distinguish bit 1, bit 2 and bit 3 from each other.

If the transmitted frames are of fixed size (which is the case of IS-95, CDMA2000 and W-CDMA) it is always possible to distinguish a command bit number from the others, because the frame itself will be the tri-bit synchronisation element.

In the cases when it is not possible to use the frame as a synchroniser, several methods (not described here) not needing extra bits have been found and can be used.

3. Overall control achievements

3.1 Response time study of the fast converging algorithm

Two analyse have been performed in order to compare the time needed to make the received level return to the best 0-5 dB range (figure 2) and the best 0-0.5 dB range (figure 3), using the classical and the FCA method.

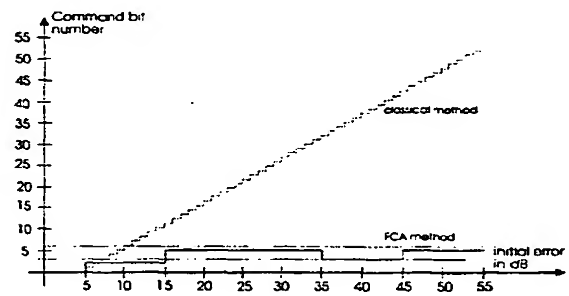

Figure 2 : command bit number necessary to return to 0-5 dB range according to an instantaneous receiving level change

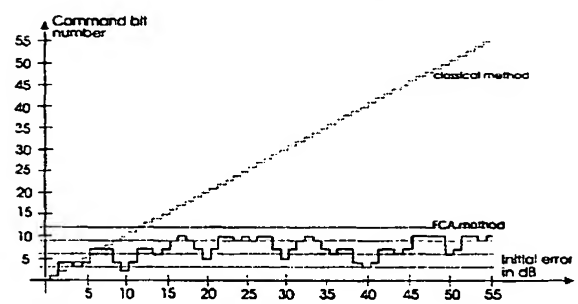

Figure 3 : command bit number necessary to return to a 0-0.5 dB range according to an instantaneous receiving level change

As can be expected, the classical method takes a time commensurate with the error to be corrected, while the FCA method takes a variable time, but comparatively independent of the correction carried out.

The study shows that the FCA algorithm needs five bits or less to bring back the error below the 5 dB level, while as many as ten bits can be needed to bring back the error below 0.5 dB.

3.2 Simulation of the control algorithms in Rayleigh fading

The previous paragraph shows clearly the speed of the FCA algorithm, but doesn't prove it's good behaviour in a real situation. This is why the two algorithms will be compared in presence of a 20 dB level drop followed without delay by a level rise of the same value and speed, these successive variations simulating a Rayleigh fading line.

Several simulation runs have been carried out by changing the duration of the drop between 40 ms and 15 ms with 5 ms steps. So, the resulting power variation rate ranges from 1 dB/ms to 2.7 dB/ms. For each simulation, maximum and mean error have been reported in figure 4.

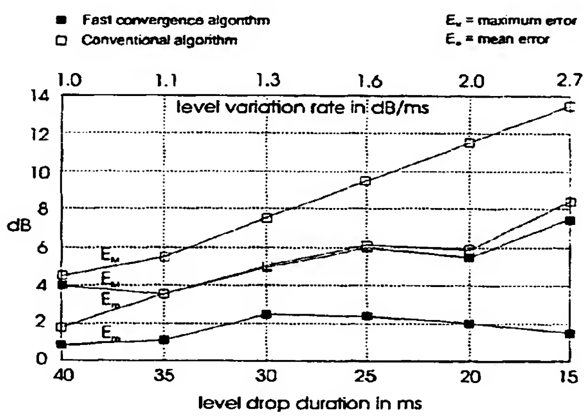

Figure 4 : Maximum and mean error during a Rayleigh fading in accordance with the correction algorithm used

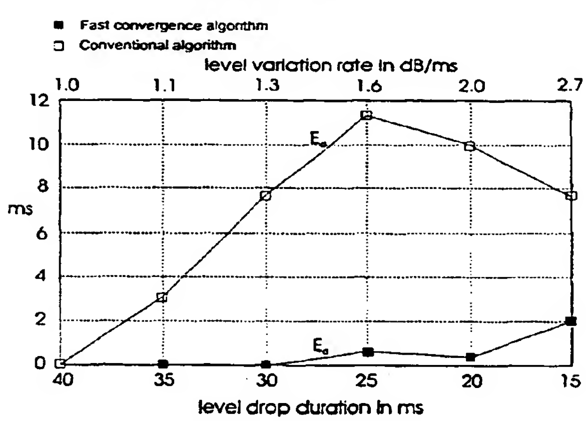

Figure 5 : Duration of a more than 5 dB error during response to a Rayleigh fading line

It is easy to see that the FCA algorithm always gives the best results, the maximum error of the former being always close to the mean error of the latter. The mean error of the FCA algorithm is fairly stable and always stays below 2.3 dB.

The time during which the error exceeds 5 dB (criterion of acceptable reception, cf. paragraph 1.3) has been represented in figure 5. With the classical algorithm the limit is exceeded about 50 % of the time as soon as the power rate change reaches 1.6 dB/ms , while this time stays negligible until a change rate of 2 dB/ms with the FCA algorithm.

3.3 Results analysis

Figure 2 clearly shows the effectiveness of the FCA algorithm. The higher the correction requested, the higher the effectiveness achieved. In the case of a 30 dB correction, 5 command bits are necessary with the FCA algorithm versus 30 with the classical algorithm.

Whatever happens, the FCA method guarantees returning to a satisfactory area after at most a 5 command bit.

Figure 3 shows that the FCA algorithm needs a nearly fixed value of about 8 command bits to come back to the 0.5 dB error area. In the case of an initial error between 2 and 6 dB, the FCA algorithm is slower than the classical algorithm, but this is without repercussion for the system working.

Figure 4 shows that with a fast drop Rayleigh line, FCA is always much better than the classical algorithm.

Figure 5 demonstrates that the FCA algorithm always keeps to the correctable reception criterion defined in paragraph 1.3 (less then 2 ms receiving error), while the classical method falls through as soon as the variation rate exceeds 1 dB/ms.

If we look beyond the immediate analysis of the curves, it is essential to bear in mind that the power control order is built with the help of a digital closed loop automatic control mechanism. When a fixed strength command is used, as with the classical method, there is very little scope to develop a high efficiency closed loop algorithm.

On the other hand, with the FCA method, the power command strength can vary between -55 dB and +55 dB. So, it is possible to develop a much better optimised closed loop algorithm. It is especially possible to have some forwarding capability by integrating a digital correction that acts like an analog derivative correction, and order intermediary corrections. These features would make possible better results than those shown in figures 4 and 5.

4. Conclusion

The Fast Convergent Algorithm (FCA) presented in the present paper can be considered as a meaningful progress in the power control of mobile devices using DS-CDMA, whatever the standard used. This result is obtained thanks to much faster response time in the case of fast variations of received level, making it possible compared to the classical method, to guarantee an error

free reception with level variation rates as much as three times higher.

An other method using Markov chains has been presented [8], nevertheless, it has a noticeably lower performance in the case of very quick and high level variations than the FCA method, and like the classical method it presents a convergence time commensurate with the correction level ordered.

One can nevertheless notice that the Markov chain method, based on an analysis of the evolution of power variation, can be combined with the FCA method. An even faster response time would result from an optimised combination of these two methods. A combination of a two bit variant of the FCA algorithm with the Markov chain algorithm gives especially interesting results because the Markov chain method would not be penalised by the latency induced by correction built with several bits.

Analyse carried out otherwise show that the best parameter values depend very much on the practical application involved and its configuration (interleaving spreading, acceptable frame error rate, frequency band used, maximum mobile speed, etc.), and alter greatly the final result. So, the numerical results given here are only directly applicable to the IS95, CDMA2000 and W-CDMA cases.

References

[1] S. Ariyavisitakul, Signal and interference statistics of a CDMA system with feedback power control, *IEEE Trans. Commun.*, volume 42 February 1994, pp. 1507-1516.

[2] R. Cameron and B. Woerner, Performance analysis of CDMA with imperfect power control, *IEEE Trans. Commun.*, volume 44, july 1996, pp. 777-771.

[3] R. C. French, The effect of fading and shadowing on channel reuse in mobile radio, *IEEE Trans. Veh. Technol.*, volume VT-28, 1979, pp. 171-175.

[4] Livingston, Donald C., *The physics of microwave propagation*, Englewoods Cliffs, NJ:Prentice Hall, 1970.

[5] Eugene Hecht, Alfred Zajac, *Optics*, Addison-Wesley Publishing Company, 1990, pp 334-378.

[6] Klein Gilhousen, Principles of CDMA, Qualcomm Inc., *IEEE conference workshop* october 5-9, 1998 Florence Italy, pp 16-17.

[7] Alexsandar M. Gogic, Overview of IMT-2000 CDMA proposals, Airtouch Communications, *IEEE conference workshop* october 5-9, 1998 Florence Italy, page 6.

[8] Hirohito Suda, Hiroyuki Kawai, Shinichi Sasaki, Fumiyuki Adachi, A fast transmit power control based on Markov transition for DS-CDMA mobile radio", *IEEE ICUPC 1998*, proceedings, pp. 235-239.